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Polarized neutron reflectometry on Co–Cr

A. van der Graaf [a,*], H. Fredrikze [a], P. de Haan [b], M.Th. Rekveldt [a], J.C. Lodder [b]

[a] *Interfacultair Reactor Instituut, TU Delft, 2629 JB Delft, The Netherlands*

[b] *MESA Research Institute, Twente University, P.O. Box 217, 7500 AE Enschede, The Netherlands*

Abstract

Polarized neutron reflectivity of a Co–Cr film on silicon with the easy axis of magnetization perpendicular to the plane has been measured at in-plane magnetic fields of various magnitudes. The obtained data can be well described assuming a constant atomic density and a gradual increase of the in-plane magnetization with depth at the different magnetic fields.

1. Introduction

Co–Cr films are candidates for perpendicular magnetic recording because of their easy axis perpendicular to the surface of the film. Polarized neutron reflectometry [1] provides information on the magnetization parallel to the polarization of the neutrons as a function of depth z. This technique measures as a function of q_0, the component of the incoming wave vector perpendicular to the surface, the intensity of specularly reflected polarized neutrons. The intensity is proportional to the square of the modulus of the reflection amplitude of the neutron wave function $\psi(z)$, which satisfies the Schrödinger equation

$$\frac{\partial^2\psi(z)}{\partial z^2}+\left(q_0^2-\Gamma(z)\right)\psi(z)=0. \tag{1}$$

$\Gamma(z)$, the neutron scattering length density as a function of z, depends on the (in-plane averaged) atomic number density, $n(z)$, the nuclear scattering length, $b_n(z)$ and the magnetic moment averaged in the direction of the polarization of the neutrons, $\mu(z)$, according to

$$\Gamma_{\pm}(z)=4\pi\langle n(z)(b_n(z)\pm C\mu(z))\rangle. \tag{2}$$

C is a constant, i.e. 2.645 fm$/\mu_B$. The + or − sign in $\Gamma(z)$ applies for neutron spin parallel or anti-parallel to the in-plane magnetic moment. Obviously $\Gamma(z)$ contains a nuclear part, Γ_n, and a magnetic part Γ_m. The latter is proportional to the magnetization in the direction of the polarization of the neutrons.

* Corresponding author. Fax: +31-15-786422; email: anja@iri.tudelft.nl.

2. Experiments

Co_{81}–Cr_{19} was rf sputtered on silicon. Fig. 1 shows the hysteresis curve of the sample as obtained by VSM-measurements. It is clear that the magnetization is non-isotropic. The specular reflection of the in-plane magnetized sample of neutrons polarized parallel and anti-parallel to the magnetization direction of the sample was measured as a function of q_0, at 'CRISP', the time-of-flight reflectometer of ISIS at the Rutherford Appleton Laboratory. The angle of incidence was 0.3°. The measurements were performed at various magnetic fields.

3. Interpretation

Fig. 2 shows the measured neutron reflectivity, not corrected for the polarization grade of the beam and for the flipper efficiency. The reflectivity of a sample can be calculated, using the so-called matrix method. This method

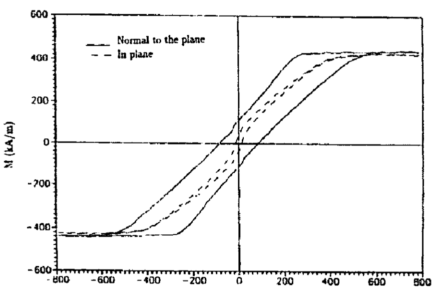

Fig. 1. Hysteresis curve of the Co–Cr film.

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assumes the sample to consist of several layers with constant Γ. The measured data at different magnetic field data are fitted simultaneously, keeping Γ_n the same for all fields. The measurements can be described assuming Γ_n to be constant with depth, resulting in $\chi^2 = 3.83$. The fits and the obtained model are given in Fig. 2 and 3 respectively. A magnitude of 0.001 nm^{-2} for Γ_m corresponds to a magnetization of 301 kA/m. The data are fitted using 5% resolution. Allowing some roughness at the interfaces did not decrease the mismatch between calculated and measured data. The value 0.0030 nm^{-2}, obtained for Γ_n for Co–Cr, agrees with the expected value. Also the value $\Gamma = 0.00264$ nm^{-2} obtained for the silicon substrate agrees with the value 0.002604 nm^{-2} as calculated from lattice-spacing [2] and the scattering length [3]. The thickness obtained by fitting the data is 140 nm. Instead of a pronounced step (so-called initial layer [4]), Fig. 3 shows a gradual increase of Γ_m with depth. The sputtered film contains more grainboundaries and has a larger variance of the easy axis of magnetization towards the substrate. The gradual increase of the in-plane magnetization at low magnetic fields can be explained by an increase of the mis-orientation of the easy axis of magnetization with depth. At higher magnetic fields the increase of the in-plane magnetization can be explained by the larger amount of grainboundaries close to the substrate. Chromium tends to dissolve in these grainboundaries. The spontaneous magnetization of Co–Cr sensitively increases with a decrease of the amount of chromium.

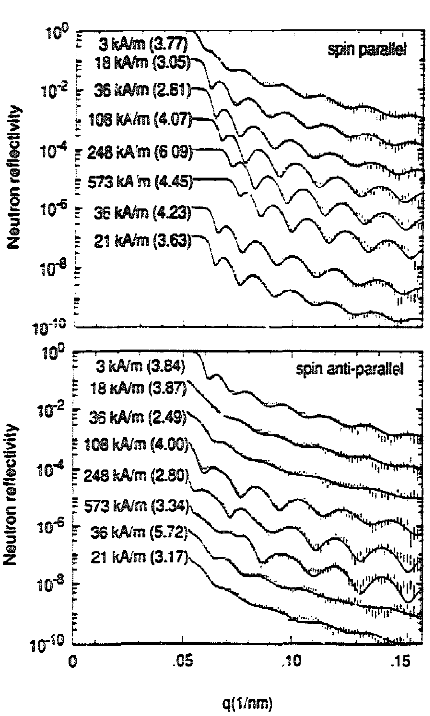

Fig. 2. Measured and fitted polarized neutron reflectivities of the Co–Cr film. The value of the magnetic field and (χ^2) of the separate curves, divided by increasing powers of 10, are given in the figure.

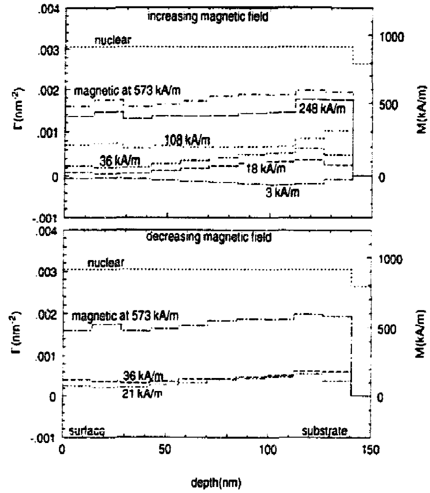

Fig. 3. The fitted models corresponding to the polarized neutron reflectivities of Fig. 2.

4. Conclusions

The measured polarized neutron reflectivity data of a Co–Cr film can well be described using a model assuming Γ_n to be constant and Γ_m increasing gradually with depth. The gradual increase of Γ_m can be understood from the structure of the Co–Cr layer.

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